

# CARDIAC RHYTHM MANAGEMENT SYSTEM FOR EDEMA

## Cross-Reference to Related Application(s)

This application is related to co-pending and commonly assigned U.S. Patent  
5 Application No. 09/832,365 entitled "CARDIAC RHYTHM MANAGEMENT SYSTEM  
FOR HYPOTENSION," filed on April 10, 2001, U.S. Patent Application No. 09/879,665  
entitled CARDIAC RHYTHM MANAGEMENT SYSTEM ADJUSTING RATE  
RESPONSE FACTOR FOR TREATING HYPTOTENSION, filed on June 12, 2001, and  
to U.S. Patent Application entitled "METHOD AND SYSTEM FOR TREATMENT OF  
10 NEUROCARDIOGENIC SYNCOPE," filed on July 27, 2001, (Attorney Docket No.  
279.318US1), the specifications of which are incorporated herein by reference in their  
entirety.

## Technical Field

15 This document relates generally to cardiac rhythm management systems and  
particularly, but not by way of limitation, to such a system for detecting and/or treating  
edema.

## Background

20 Excess fluid buildup ("edema") in a subject may be associated with many  
diseases. Edema results from inadequate or excessive response of homeostatic processes  
in the body. For example, acute pulmonary edema is a short-term fluid buildup in the  
lungs. In some people, such excess fluid buildup (also referred to as "decompensation")  
results from inadequate cardiac output of the heart, such as is associated with congestive  
25 heart failure ("CHF"). Pulmonary edema may occur late in the CHF disease process and,  
therefore, may have serious consequences. The fluid accumulation in the lungs may  
result in labored breathing and, in severe cases, may even result in death. For these and  
other reasons, there is a need to detect edema and, more importantly, to provide  
appropriate responsive therapy to treat edema and/or any underlying heart condition  
30 causing the edema.

## **Summary**

This document discusses a cardiac rhythm management system that detects edema. In response to an episode of detected edema, it initiates and/or adjusts a cardiac resynchronization therapy and/or a cardiac contractility modulation (CCM) therapy.

5 One example discusses a cardiac rhythm management system. The system includes an edema detection circuit to sense a condition correlative to edema in a subject. An electrical energy delivery circuit delivers electrical energy to the subject. A controller is coupled to the edema detection circuit to receive a detected edema indicator. The controller is also coupled to the energy delivery circuit to provide a  
10 control signal for timing delivery of the electrical energy to the subject. The controller includes a cardiac resynchronization therapy mode and a cardiac contractility modulation therapy mode. The controller is configured, in response to the detected edema indicator, to perform at least one of: initiating/adjusting the cardiac resynchronization therapy; and, initiating/adjusting the cardiac contractility modulation  
15 therapy. Other aspects of the invention will be apparent on reading the following detailed description of the invention and viewing the drawings that form a part thereof.

## **Brief Description of the Drawings**

In the drawings, which are not necessarily drawn to scale, like numerals  
20 describe substantially similar components throughout the several views. Like numerals having different letter suffixes represent different instances of substantially similar components.

Figure 1 is a block diagram example of portions of a cardiac rhythm management system and portions of an environment in which it is used.

25 Figure 2 is a block diagram example of one possible edema detection circuit.

Figure 3 is a block diagram example of portions of a possible signal processor.

Figure 4 is a block diagram example of one possible edema detection module.

Figure 5 is a block diagram example of an alternative edema detection module.

Figure 6 is a block diagram example of an alternative signal processing circuit

that determines whether edema is present based not only on the baseline thoracic impedance signal, but also on an additional breathing rate criterion.

Figure 7 is a block diagram example in which a cardiac rhythm management device is associated with a heart at both an atrium (right or left) and a ventricle (right or left).

- 5           Figure 8 is a block diagram example in which various responses to a detected edema episode are prioritized.

### **Detailed Description**

- 10           In the following detailed description, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that the embodiments may be combined, or that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the spirit and scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims and their equivalents.

- 20           Figure 1 is a block diagram example of portions of one possible cardiac rhythm management system **100** and portions of an environment in which it is used. In this example, system **100** includes, among other things, a cardiac rhythm management device **102** and leadwire (“lead”) **104**. Leadwire **104** is coupled to device **102** for communicating one or more signals between device **102** and a portion of a living organism or other subject, such as heart **106**. Some examples of device **102** include, among other things, bradycardia and antitachycardia pacemakers, cardioverters, 25   defibrillators, combination pacemaker/defibrillators, cardiac resynchronization therapy devices, and drug delivery devices. Other examples of device **102** include any other implantable or external cardiac rhythm management apparatus capable of providing cardiac rhythm management therapy to heart **106**. Such cardiac rhythm management therapy is not limited to managing cardiac rate. For example, cardiac rhythm

management therapy also includes cardiac resynchronization therapy. Cardiac resynchronization therapy typically coordinates the spatial nature of a depolarization associated with a heart contraction in one or more heart chambers. While such cardiac resynchronization therapy may modify cardiac rate, it can also occur without any modification of the rate at which heart contractions occur. Some examples of cardiac resynchronization therapy include simultaneous or offset multichamber (e.g., biventricular) pacing and/or simultaneous or offset delivery of pacing pulses to multiple electrodes associated with a single heart chamber. Moreover, the cardiac rhythm management therapy discussed in this document also includes cardiac contractility modulation (CCM) therapy. CCM therapy includes delivering electrical energy to a portion of the heart during a refractory time period when that portion of the heart is relatively unlikely to contract in response to the received electrical energy. Therefore, CCM therapy need not adjust cardiac rate and, moreover, need not even evoke responsive heart contractions. System 100 may also include additional components such as, for example, an external or other remote interface 108 capable of communicating with device 102.

In this example, device 102 includes, among other things, a microprocessor or other controller 110 coupled to an edema detection circuit 112, an electrical energy output circuit 114, and a communication circuit 118. Communication circuit 118 is adapted for wireless or other communication with remote interface 108. Electrical energy output circuit 114 is coupled to one or more electrodes associated with any chamber(s) of heart 106, such as electrodes 120 and 122 of lead 104. Such electrodes deliver electrical pacing stimulations for evoking responsive heart contractions or for delivering cardiac contractility modulation (“CCM”) energy pulses, which do not evoke responsive heart contractions, as discussed below.

In this example, edema detection circuit 112 detects a condition in the subject that is correlative to an episode of edema, and outputs a responsive edema indicator to controller 110. In one response to the detected edema, controller 110 initiates or adjusts a cardiac resynchronization therapy. In another response to the detected edema, controller 110 initiates or adjusts a CCM therapy. In a further example of operation,

controller **110** communicates an indication of the detected edema through communication circuit **118** to remote interface **108** for visible display or for other user output.

Figure **2** is a block diagram example of one possible edema detection circuit **112** that senses thoracic impedance to determine whether the edema condition is present. In this example, edema detection circuit includes exciter **200** and signal processor **202**, both of which are coupled to electrodes associated with a portion of the subject's thorax. In this document, the term "thorax" refers to the subject's body other than the subject's head, arms, and legs. Exciter **200** provides, at node/bus **204**, a test signal to the thorax, from which thoracic impedance is determined. Exciter **200** need not, and typically does not, stimulate tissue or muscle contractions in the thorax; it is referred to as an exciter because it provides a test excitation signal for determining impedance. Signal processor **202** receives from the thorax, at node/bus **206**, signals responsive to the test signal provided by exciter **200**. Signal processor **202** outputs, at node/bus **208**, the edema indicator to controller **110**.

The thoracic electrodes associated with exciter **200** may be different from the thoracic electrodes associated with signal processor **202**. For example, one such suitable electrode configuration for sensing thoracic impedance includes the configuration of at least four electrodes for detecting thoracic impedance, such as discussed in Hauck et al. U.S. Patent 5,284,136 entitled "DUAL INDIFFERENT ELECTRODE PACEMAKER," assigned to Cardiac Pacemakers, Inc., the disclosure of which is incorporated herein by reference in its entirety. However, a different number of electrodes (e.g., 2 or 3 electrodes, or more than 4 electrodes) could also be used. Therefore, in another example, one or more of the thoracic electrodes of edema detection circuit **112** is shared by both exciter **200** and signal processor **202**.

In one example, exciter **200** and signal processor **202** cooperate to detect thoracic impedance using a high frequency carrier signal to provide the test stimulus that obtains the thoracic impedance response, as discussed in Hartley et al. U.S. Patent No. 6,076,015 ("the Hartley et al. patent") entitled "RATE ADAPTIVE CARDIAC RHYTHM MANAGEMENT DEVICE USING TRANSTHORACIC IMPEDANCE,"

assigned to Cardiac Pacemakers, Inc., the disclosure of which is incorporated herein by reference in its entirety.

Figure 3 is a block diagram example of portions of a possible signal processor 202. The input signal from the thoracic electrodes, which is responsive to the test stimulus provided by exciter 200, is received by an analog signal processing circuit 300 at its preamplifier 302 circuit. A signal provided by an output of preamplifier 302 is received by a demodulator 304 circuit. Demodulator 304 demodulates the high frequency carrier signal to extract thoracic impedance information. A signal provided by an output of demodulator 304 is received by analog-to-digital (A/D) converter 306, where it is converted into a digital thoracic impedance signal. Suitable examples of preamplifier 302, demodulator 304, and A/D converter 306 are discussed in the Hartley et al. patent, which was above incorporated by reference in its entirety.

In this example, the digitized signal provided by A/D converter 306 undergoes further signal processing in the digital domain by digital signal processing circuit 308, which includes a lowpass filtering or averager 310 receiving the digital output signal from A/D converter 306. The digitized thoracic impedance signal is influenced not only by the amount of fluid in a subject's thorax, but also by the subject's heart beat (referred to as the "cardiac stroke" signal component) and the subject's breathing (also referred to as the "respiration" or "ventilation" component). Lowpass filter or averager 310 extracts the "dc" or "baseline" or "low frequency" component of the thoracic impedance signal (e.g., less than a cutoff value that is approximately between 0.1 Hz and 0.5 Hz, inclusive, such as, for example, a cutoff value of approximately 0.1 Hz). The baseline component of the thoracic impedance signal provides information about the amount of fluid in the subject's thorax. A decrease in the baseline thoracic impedance indicates the thoracic fluid accumulation condition associated with edema. In providing the baseline thoracic impedance output signal, lowpass filter or averager 310 attenuates the higher frequency components of the thoracic impedance signal that are influenced by the patient's breathing (e.g., approximately between 0.05 Hz and 2.0 Hz inclusive) and heartbeat (e.g., approximately between 0.5 Hz and 10 Hz inclusive). Digital signal processing circuit 308 also includes an edema detection module 312

which determines whether the baseline impedance signal received from lowpass filter or averager **310** indicates that edema is present in the subject, and provides the resulting edema indicator at node **208** to controller **110**.

Figure **4** is a block diagram example of one possible edema detection module **312**. It includes a delay **400** that outputs a long-term value of the lowpass-filtered thoracic impedance, that is, the baseline thoracic impedance including information about fluid shifts to and away from the thorax. Comparator **402** compares the substantially instantaneous and long-term values of the baseline thoracic impedance at its respective comparator inputs. If the substantially instantaneous baseline thoracic impedance is less than the long-term value of the baseline thoracic impedance by a predetermined threshold value, then comparator **402** provides a resulting signal, at node **208**, that indicates that edema is present. Otherwise, the resulting signal at node **208** indicates that edema is not present.

Figure **5** is a block diagram example of an alternative edema detection module **312**. In this example, comparator **402** compares the unfiltered thoracic impedance from the output A/D converter **306** to the lowpass-filtered thoracic impedance (i.e., the baseline thoracic impedance) from the output of lowpass filter or averager **310**. If the unfiltered thoracic impedance from A/D converter **306** is less than the baseline thoracic impedance from lowpass filter or averager **310** by a predetermined threshold value, then comparator **402** provides the resulting signal, at node **208**, that indicates that edema is present. Otherwise, the resulting signal at node **208** indicates that edema is not present.

Figure **6** is a block diagram example of an alternative signal processing circuit **202** that determines whether edema is present based not only on the baseline thoracic impedance signal, but also on an additional breathing rate criterion. In the example of Figure **6**, the digitized thoracic impedance signal from A/D converter **306** is also received at an input of bandpass filter **600**. Bandpass filter **600** attenuates frequencies outside the frequency range associated with the breathing component of the thoracic impedance signal (e.g., approximately between 0.05 Hz and 2.0 Hz inclusive). Bandpass filter **600** outputs a signal correlative to the subject's breathing, which is

received at an input of breathing rate module **602**. Breathing rate module **602** includes a fiducial point detector (e.g., zero-cross detector, level detector, peak detector, etc.) detecting a fiducial point on the breathing signal that occurs a known number of one or more times during breathing cycle (of inhaling and exhaling). A timer measures the time interval between respective successive fiducial points, from which the breathing rate is determined. A comparator compares the breathing rate to a threshold value that is approximately between 10 breaths per minute and 40 breaths per minute, such as about 25 breaths per minute. Breathing rate module **602** outputs at node **604** a digital signal indicating whether the breathing rate threshold is being exceeded. This signal is used (e.g., by AND gate **606**) to qualify the signal output from edema detection module **312**. Therefore, the edema-present indicator at node **208** is asserted only if both the baseline thoracic impedance indicates a fluid accumulation in the thorax and the breathing rate exceeds the threshold value.

In a further example, in which device **102** includes an activity sensor (such as, for example, an accelerometer), the signal output from edema detection module **312** is further qualified by a digital signal indicating whether the patient is resting. This is determined by comparing the activity level indicated by the activity sensor to a threshold value. The patient is deemed to be resting when the activity level is less than the threshold value. In such an example, AND gate **606** is implemented as a 3-input AND gate, with a first input receiving the output of edema detection module **312**, a second input receiving the output of breathing rate module **602**, and a third input receiving a signal, based on the comparison of the activity level to the threshold value, that is a logical "1" if the patient is resting. The output of the 3-input AND gate is communicated, at node **208**, to controller **110**. In this example, the edema-present indicator at node **208** is asserted only if both the baseline thoracic impedance indicates a fluid accumulation in the thorax and the resting breathing rate exceeds the threshold value.

When the edema indicator received at node **208** by controller **110** indicates that edema is present, controller **110** responds by initiating or adjusting a therapy provided to heart **106**. In one example, controller **110** responds to an edema detection by



initiating or adjusting a cardiac resynchronization therapy that coordinates the spatial nature of a depolarization associated with a heart contraction in one or more heart chambers. Figure 7 is a block diagram example in which device **102** is associated with heart **106** at both an atrium (right or left) and a ventricle (right or left) for sensing and/or pacing atrial and/or ventricular heart contractions occurring during the same cardiac cycle (of an atrial and subsequent ventricular contraction). The atrial contraction and the subsequent ventricular contraction occurring during the same cardiac cycle are separated by a time interval that is referred to as an atrioventricular (AV) delay. In one example of adjusting a cardiac resynchronization therapy in response to detected edema, controller **110** adjusts the AV delay value stored in a memory location of controller **110**. In one example, the AV delay value is programmable by the user to be approximately between 20 milliseconds and 200 milliseconds, such as about 100 milliseconds. In response to the detected edema, controller **110** incrementally adjusts, over a suitable period of time for allowing the edema to abate, the AV delay to a shorter or longer value until the edema abates or all possible AV delay values have been exhausted.

In an example of initiating a cardiac resynchronization therapy in response to the detected edema, controller **110** switches from pacing a single ventricle (e.g., the right ventricle) to biventricular pacing of electrodes associated with each of the right and left ventricles. One suitable electrode configuration for biventricular pacing includes at least one intravascular electrode in the right ventricle and at least one other intravascular electrode introduced into the coronary sinus and/or great cardiac vein into association with the left ventricle. The biventricular pacing includes simultaneous delivery of pacing stimuli to both ventricles. The biventricular pacing also includes delivering such pacing stimuli in different ventricles at different times that are separated by an interventricular delay.

In an example of adjusting a cardiac resynchronization therapy in response to the detected edema, such as when biventricular pacing therapy is already being provided, controller **110** adjusts the value of the interventricular delay. In one example, the interventricular delay value is programmable by the user to be approximately

between 20 milliseconds and 200 milliseconds, such as about 100 milliseconds. In response to the detected edema, controller 110 incrementally adjusts, over a suitable period of time for allowing the edema to abate, the interventricular delay value to a shorter or longer value until the edema abates or all possible interventricular delay values have been exhausted.

- 5           In another example of adjusting a cardiac resynchronization therapy in response to the detected edema, such as when multiple electrodes are associated with a single heart chamber, is to select a different one of the same-chamber electrodes for providing the pacing stimulations associated with that heart chamber. One such possible electrode configuration includes two coronary sinus and/or great cardiac vein
- 10 electrodes associated with the different locations of the left ventricle. In this example, the left ventricular electrodes are positioned for association with different locations in the left ventricle. For example, such left ventricular electrodes may be positioned in apical, midregion, and basal left ventricular locations. In this example, when left ventricular pacing therapy is being delivered from one of the left ventricular electrodes
- 15 (with or without corresponding right ventricular pacing therapy), controller 110 responds to the detected edema by shifting to a different left ventricular electrode for providing pacing therapy. In a further example, when left ventricular pacing therapy is being delivered at more than one left ventricular electrode, controller 110 responds to an edema detection by adjusting an interelectrode delay between delivery of the pacing
- 20 pulses at the different left ventricular electrodes. In one example, the interelectrode delay between delivery of the pacing pulses at the left ventricular electrodes is programmable by the user to values ranging approximately between -100 milliseconds and +100 milliseconds, such as about zero milliseconds. In response to the detected edema, controller 110 incrementally adjusts, over a suitable period of time for allowing
- 25 the edema to abate, the interelectrode delay value to a shorter or longer value until the edema abates or all possible interelectrode delay values (or, for more than two same-chamber electrodes, all possible combinations of interelectrode delay values) have been exhausted.

In another example, controller 110 responds to an edema detection by initiating

or adjusting cardiac contractility modulation (CCM) therapy, such as by using an excitable tissue controller (ETC). CCM therapy includes delivering electrical energy to a portion of the heart during a refractory time period when that portion of the heart is relatively unlikely to contract in response to the received electrical energy. Therefore, CCM therapy need not adjust cardiac rate and, moreover, need not even evoke responsive heart contractions. The electrical energy delivered during the CCM therapy causes an increase in myocardial contractility of the heart muscle, presumably by increasing intracellular calcium concentration. The CCM increase in contractility in turn increases the stroke volume of the heart contractions, so that more blood is pumped by a subsequent systolic contraction. This counteracts and assists in abating the detected edema. Examples of refractory time periods suitable for initiating delivery of CCM therapy include, by way of example, but not by way of limitation, a time period that is approximately between 1 millisecond and 70 milliseconds following an activation (the CCM energy pulse may, in some examples, extend beyond this refractory time period during which the CCM energy pulse is initiated). In one example, the CCM therapy includes electrical energy pulses, each such pulse having an energy that is, by way of example, but not by way of limitation, approximately between 50 microJoules and 500 microJoules. In one example, the CCM energy pulses are delivered as current pulses, each current pulse having an amplitude that is, by way of example, but not by way of limitation, approximately between 0.5 milliamperes and 20 milliamperes, and each current pulse having a pulsewidth that is, by way of example, but not by way of limitation, approximately between 10 milliseconds and 140 milliseconds. In one example, controller 110 responds to an edema detection by initiating CCM therapy delivered, by way of example, but not by way of limitation, from electrode(s) associated with one or both ventricular heart chambers.

25 In another example, controller 110 responds to the edema detection by adjusting a parameter associated CCM therapy already being delivered, such as by incrementally increasing the energy (e.g., amplitude and/or pulsewidth) from its programmed value to a higher value until the edema abates or all available increased energy levels have been exhausted.

Figure 8 is a block diagram example in which various responses to a detected edema episode are prioritized. In this example, controller 110 sequentially attempts the various edema-response measures in the order of priority until the edema abates or all possible responses have been exhausted.

- It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-discussed embodiments may be used in combination with each other. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.”

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